



# **Status of HCAL Simulation and Software**

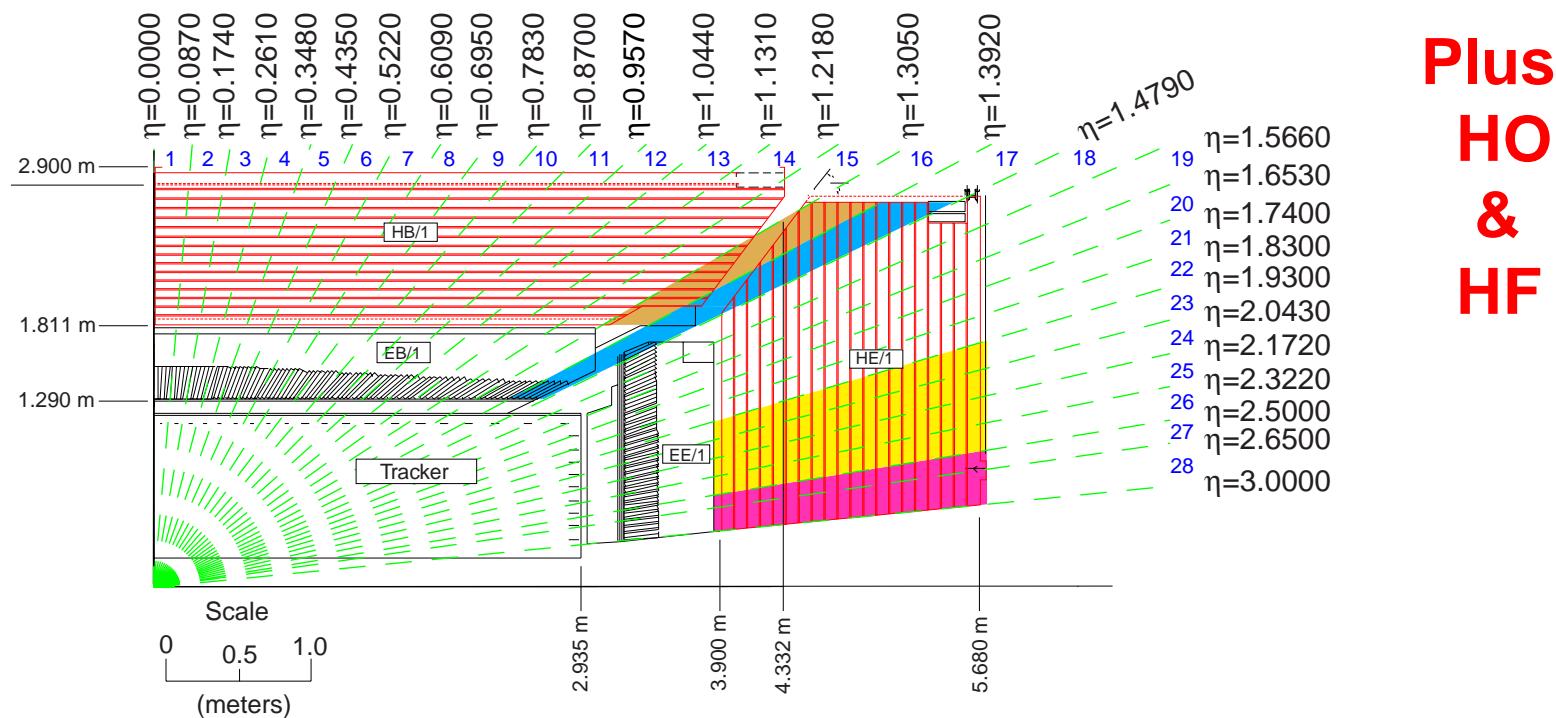
**Shuichi Kunori**  
**Univ. Of Maryland**  
**(kunori@fnal.gov)**

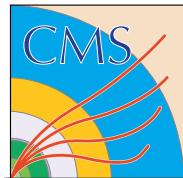


# CMS Calorimeter

## Hadron Calorimetry

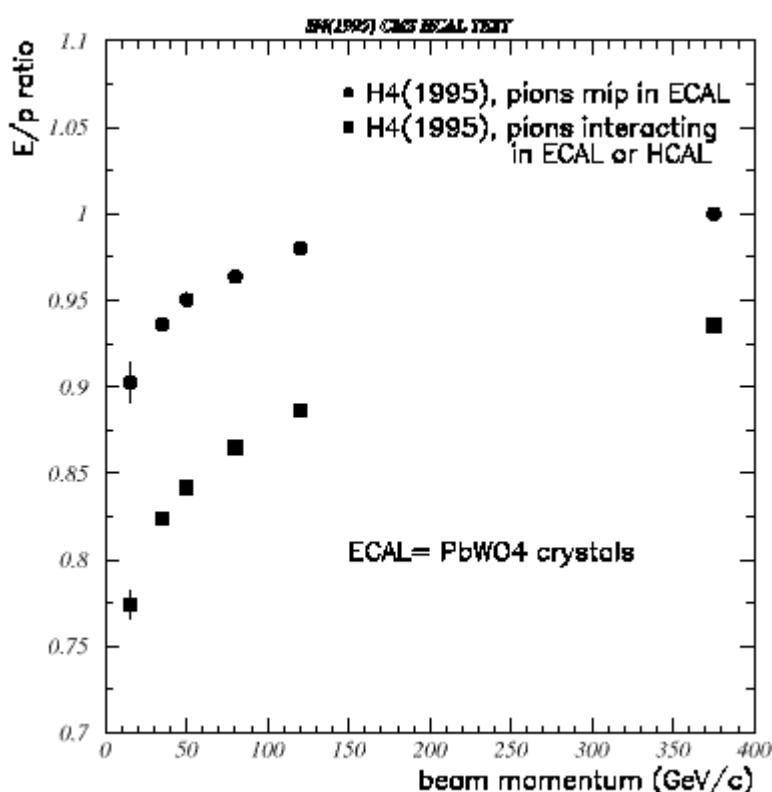
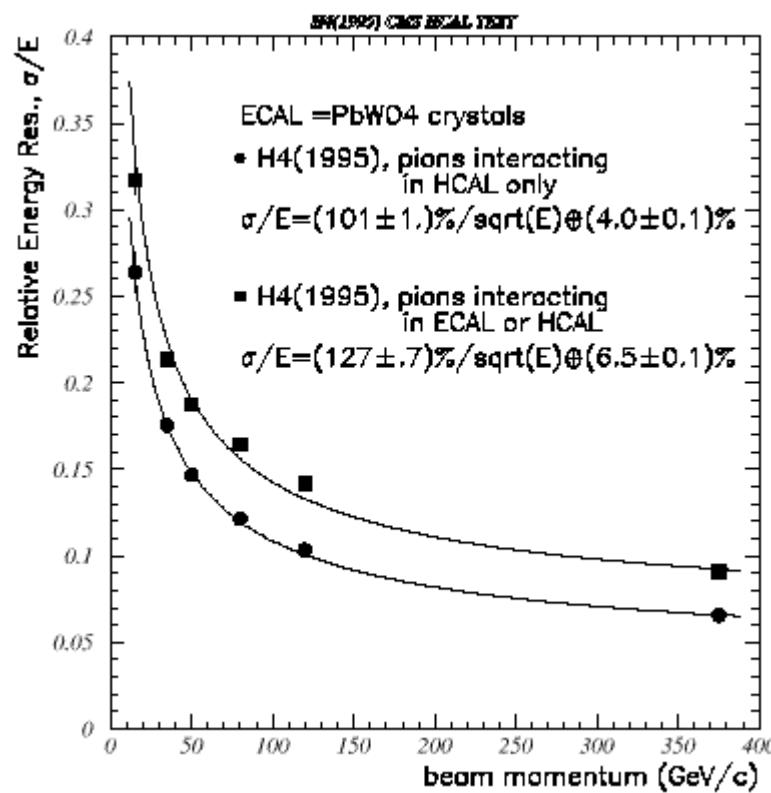
- Jets
- MET(missing Et)





# Single Particle Response

## 1995 Test Beam Data



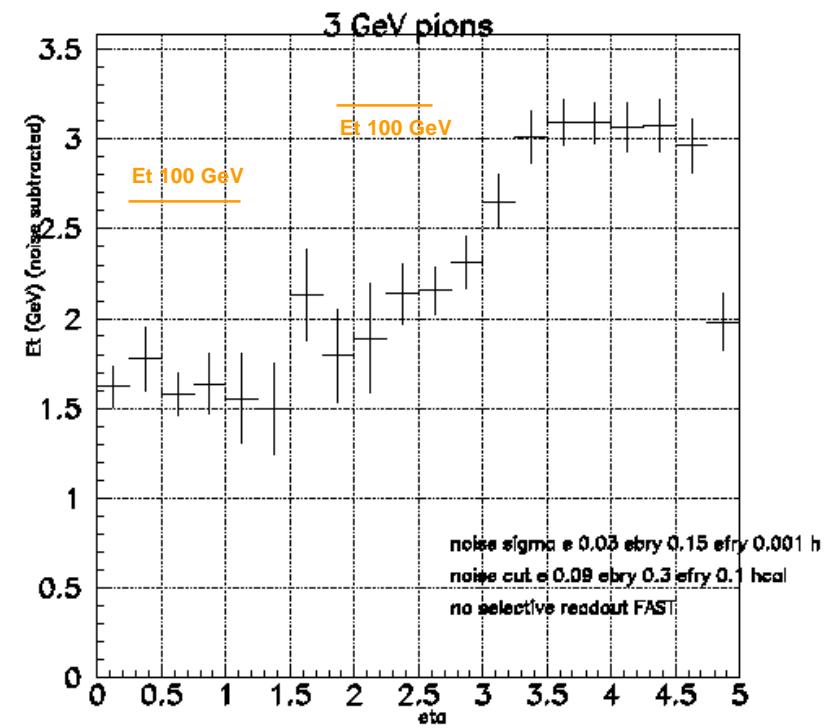
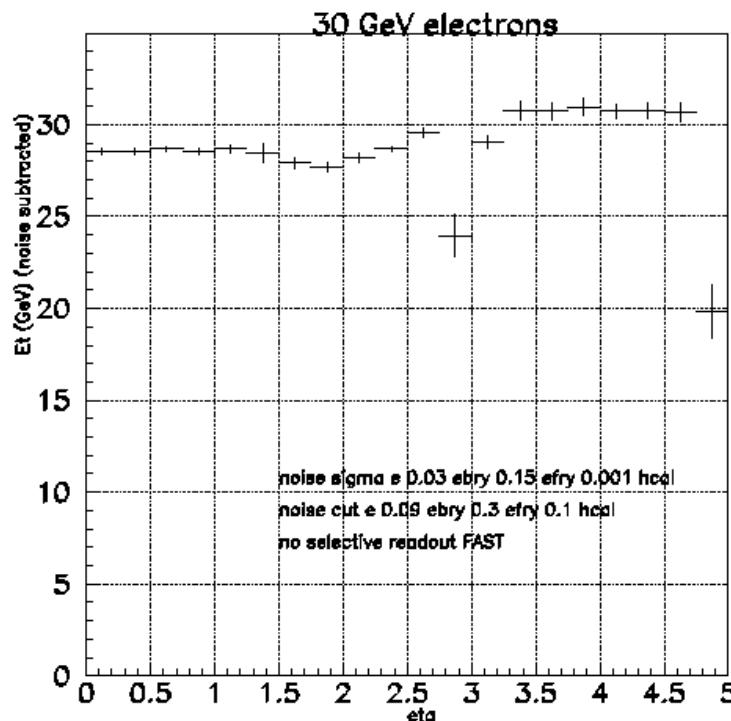
2cm Cu + 9x3cm Cu + 9x6cm Cu + 8cm Cu + 29cm Al (coil) + 2x8cm Cu + 2x10cm Cu  
(no field)



# Single Particle in CMS

## Energy Scale

- HB,HE with  $E_T = 50\text{GeV}$  pions into HCAL
- HF with  $E = 1\text{TeV}$  jet



E= 3      7      30      82      227 GeV

(These plots were made with ORCA3 by S.Eno)



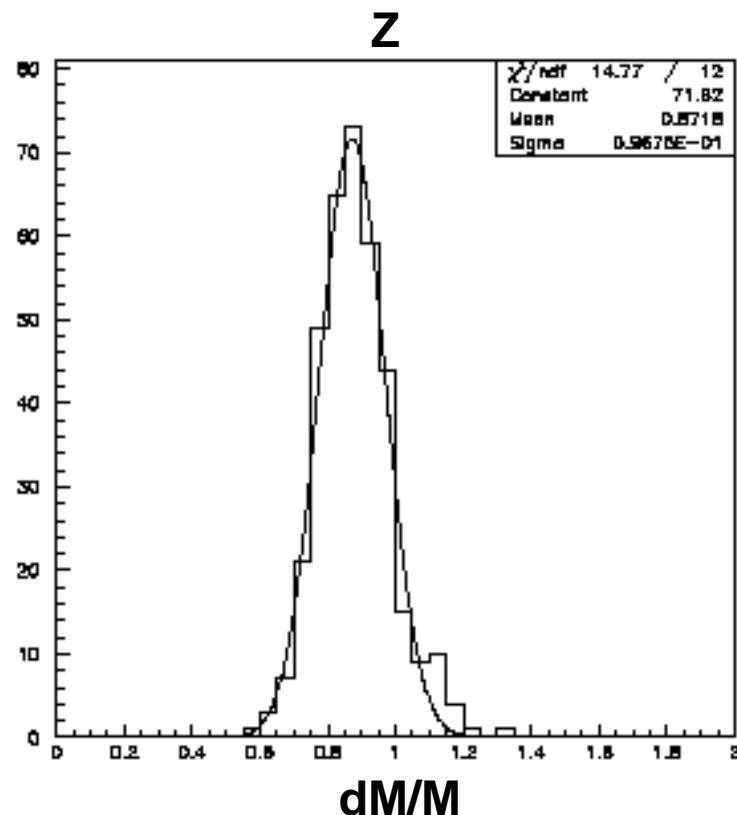
# Jet Response

Need a good plot  
on resolution here!

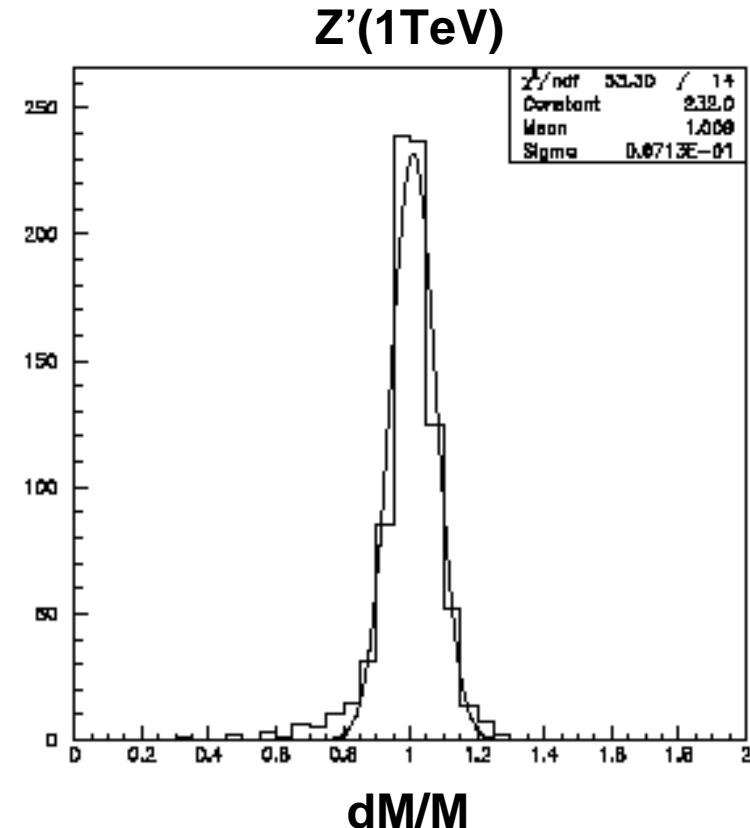
Need a good plot  
on linearity here!



# Di-jets Mass

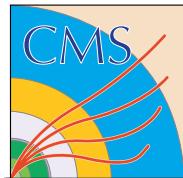


shift -13%  
sigma 9.7%



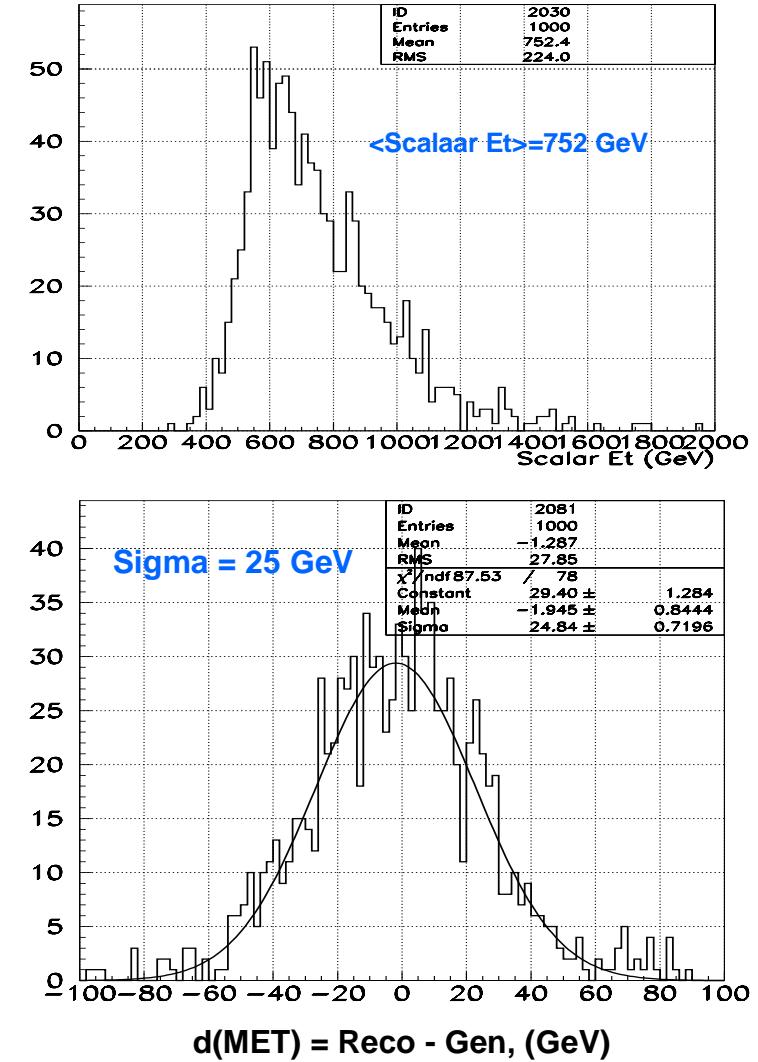
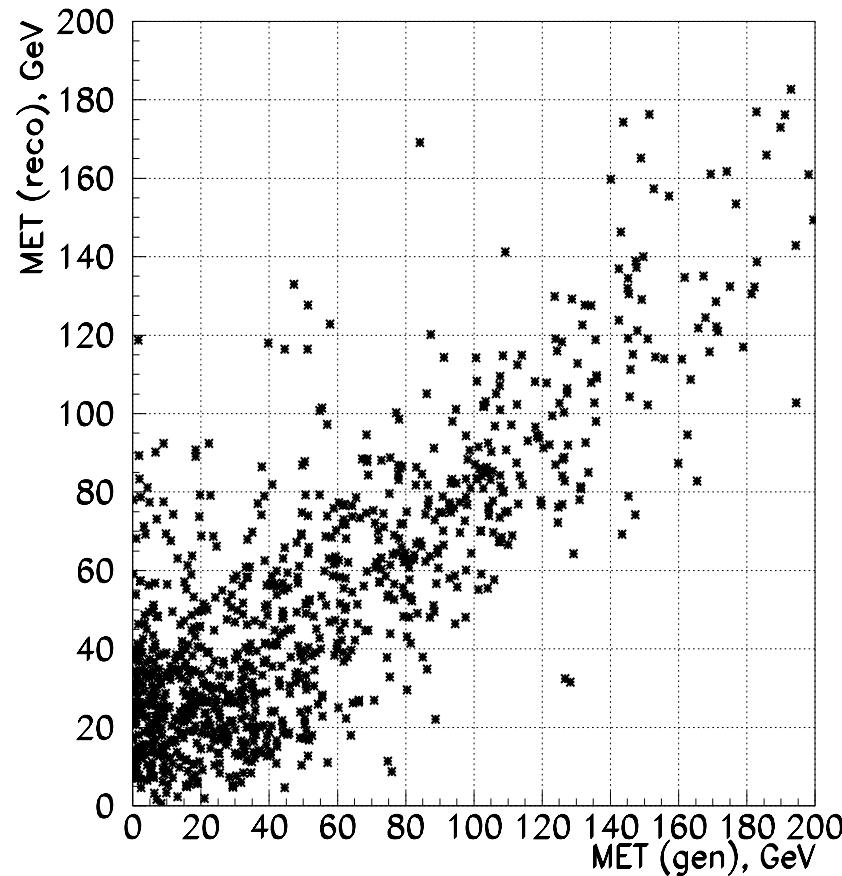
shift +1%  
sigma 6.7%

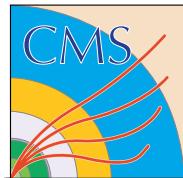
(Note: initial & final state radiation were turned off in PYTHIA generation.)



# MET Response

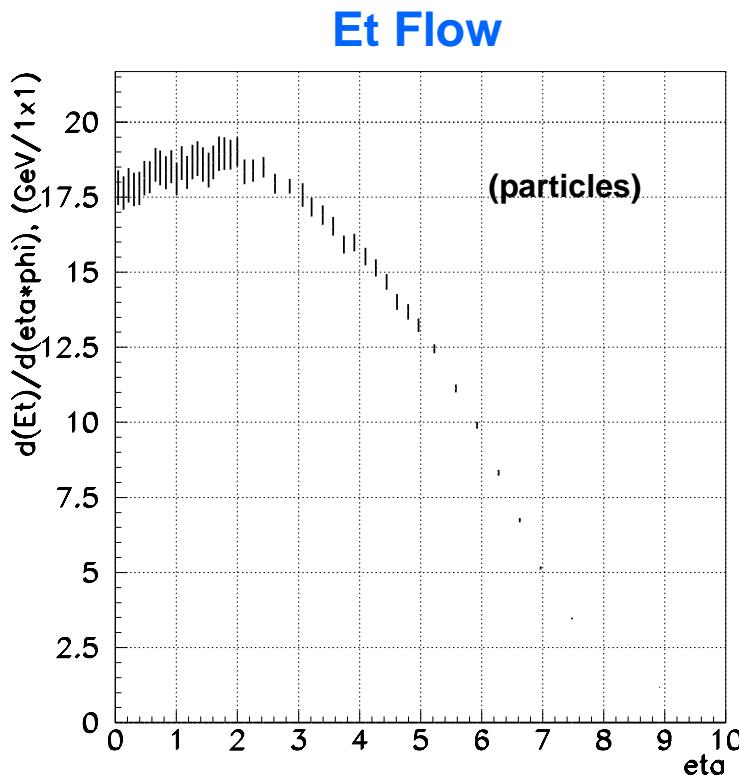
**ttH(110)** no min-bias overlap



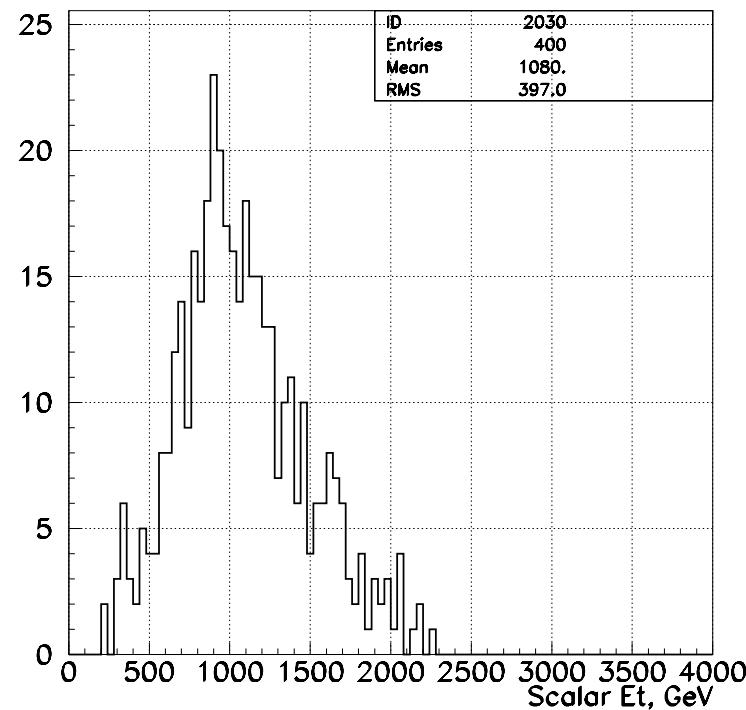


# Minimum Bias Event Overlap

X-sec = 55mb >>> 17.3 min-bias/crossing at 10E34



**Scalar Et ( eta<5 )**



~17 GeV in unit (eta x phi) !

( equiv. cone radius 0.56 )

<Scalar Et> = 1080 GeV

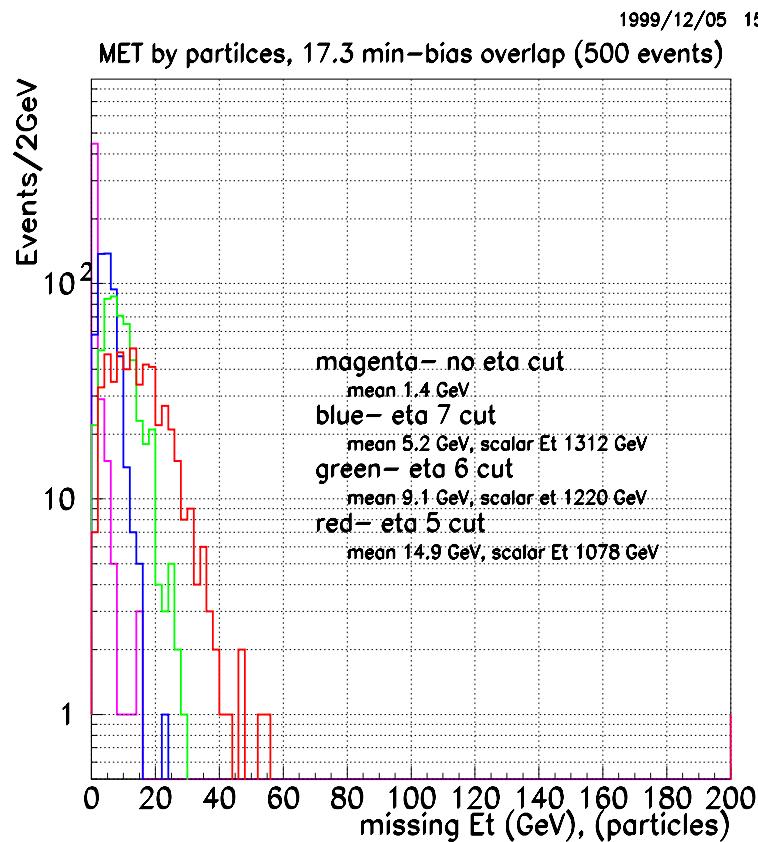
Note: <Scalar Et> = 750 GeV for ttH



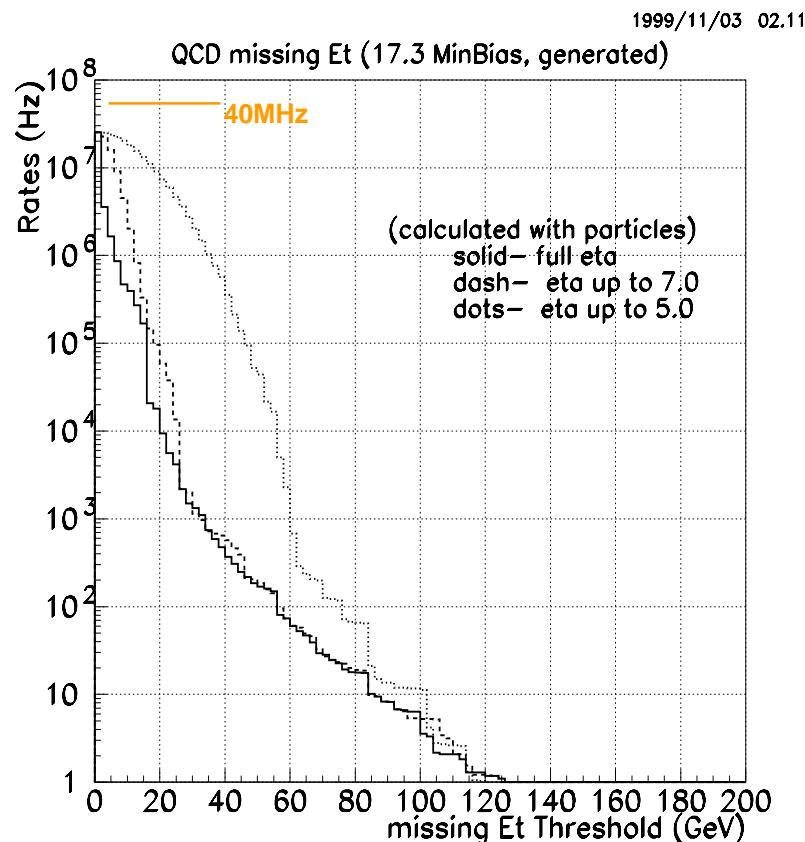
# MET: Eta 5 vs Eta 7

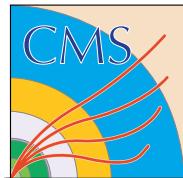
(Event Generator Level)

17.3 Min-bias events



Rates for QCD  $\text{Et} > 15\text{GeV}$  + min-bias.



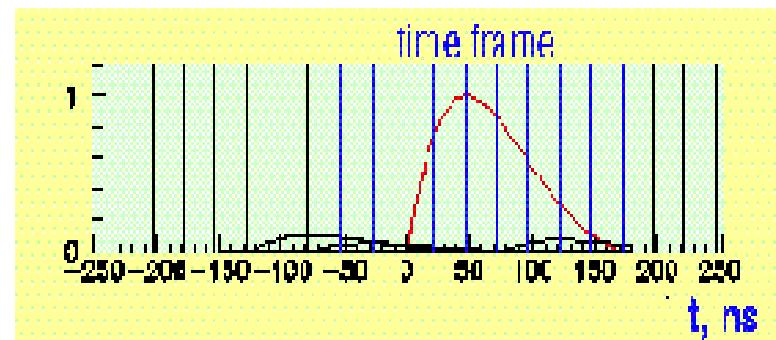


# Beam Crossing- 25nsec.

HB, HE signal pulse is longer than 25 nsec.!

Probably  
3 crossing (out of 5) to get  
full energy.

How about HF?



Source:

Time constant of the readout electronics.

Time constant of wave length shift fibers.

Particles curling in the tracker volume in 4 Tesla field.

Slow neutrons in hadron shower.

Plan: (this year)

QIE test

Simulation with CMSIM-ORCA



# Other Issues

## 4 Tesla field:

- shift of charge particles in eta-phi (calorimeter)
  - smearing in MET measurement
  - energy leakage to the outside of Jet cone.

## Electronics noise:

- random: EB(EE) noise 30 (150) MeV / crystal
- coherent: killer in the test beam!

## Material before Calorimeter:

- cables, pipes in tracker volume
  - Interaction length may not be really negligible.

## Heavy Ion:

- ??? (I hope to learn this this time.)



# Some Physics Performance Study for Jets/MET (using CMSIM)

## Di-jets from Z and Z'

(CMS Note 1998/026)

- jet energy resolution and di-jet mass resolution

## H(170GeV) -> WW -> 2 lep + 2 nu

(CMS Note 1998/089)

- bg: WW(continuum), tt
- sample: 5 fb<sup>-1</sup>
- jet veto (~20GeV), MET (~ 20GeV balanced to 2 lep)

## Single Top production

(CMS Note 1999/048)

- bg: tt, Wjj, Wjjj
- sample 10 fb<sup>-1</sup>
- jet (20/50 GeV central/forward), MET (20GeV) & b tag

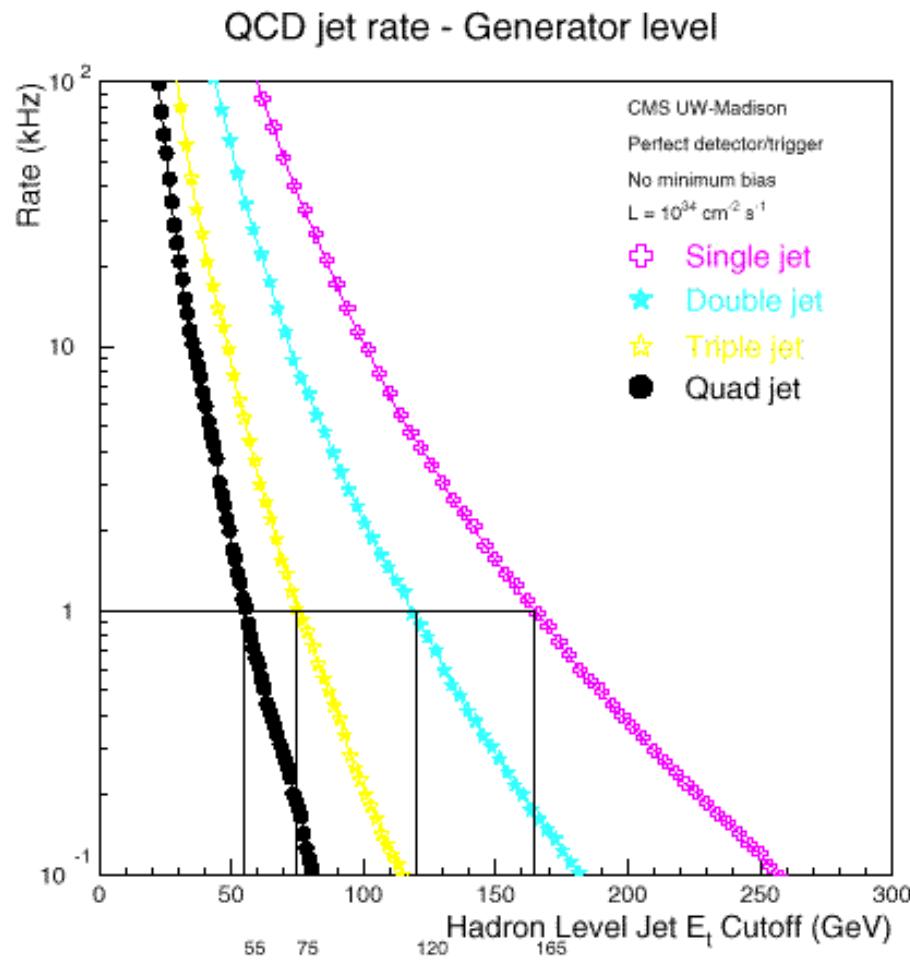
## ttH(110-120GeV)

(in progress)

- bg: ttbb
- multi jets ( 8 jets at most) & b tag



# QCD Jet Rate



**Very High rate!**

1 kHz = acceptable L1 rate for jets

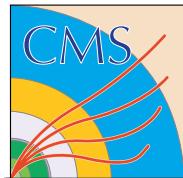
- **1 jet 165 GeV**
- **2 jets 120 GeV**
- **3 jets 75 GeV**
- **4 jets 55 GeV**

**Trigger Output (max):**

- **L1 75 kHz**
  - (3 kHz for Jets)
- **L2 1 kHz**
- **L3 100 Hz (to tape)**

**How to stay below 100 Hz ?**

Guideline: 20Hz for Jets, MET, combination.



# Example Cuts

Draft list of processes where low Pt jet trigger could be required

#	Process	Typical physics cuts	Trigg. L1 (95% eff.?)
1	W (l v) + H (b $\bar{b}$ )	1 l (I), $E_t > 20$ , $  \eta   < 2.5$ 2 bj, $E_t > 25$ , $  \eta   < 2.5$ $E_t^{\text{miss}} > 20$	$E > 15$ or $M > 15$ $  \eta   < 2.5$ 2 J > 25 $  \eta   < 2.5$
2	t $\bar{t}$ (l v + X) + H (b $\bar{b}$ )	1 l (I), $E_t > 20$ , $  \eta   < 2.5$ 4 bj + 2 j, $E_t > 25$ , $  \eta   < 2.5$ $E_t^{\text{miss}} > 20$	$E > 15$ or $M > 15$ $  \eta   < 2.5$ 2 J > 25 $  \eta   < 2.5$
3a	h,H,A ( $\tau \tau$ ) $\rightarrow$ h + h + X	1 l (I), $E_t > 20$ , $  \eta   < 2.5$ 1 hj, $E_t > 40$ , $  \eta   < 2.5$ $E_t^{\text{miss}} > 20$	$E > 15$ or $M > 15$ $  \eta   < 2.5$ T > 40 $  \eta   < 2.5$
3b	+ tag. jet(s)	1- 2 j, $E_t > 25$ , $2 <   \eta   < 4.5$	J > 25 $2 <   \eta   < 4.5$
4a	h,H,A ( $\tau \tau$ ) $\rightarrow$ h + h + X	2 hj, $E_t > 60$ , $  \eta   < 2.5$ $E_t^{\text{miss}} > 40$	2T > 60 $  \eta   < 2.5$
4b	+ tag. jet(s)	1- 2 j, $E_t > 25$ , $2 <   \eta   < 4.5$	J > 25 $2 <   \eta   < 4.5$
5	qqH $\rightarrow$ W (l v) W (q q) + tag. jet(s)	1 l (I), $E_t > 50$ , $  \eta   < 2.5$ 1-2 j, $E_t > 40$ , $  \eta   < 2.5$ $E_t^{\text{miss}} > 150$ 1- 2 j, $E_t > 25$ , $2 <   \eta   < 4.5$	$E > 30$ or $M > 30$ $  \eta   < 2.5$
6	t $\bar{t}$ (l v + X)	1 l (I), $E_t > 20$ , $  \eta   < 2.5$ 2 bj + 2 j, $E_t > 25$ , $  \eta   < 2.5$ $E_t^{\text{miss}} > 20$	$E > 15$ or $M > 15$ $  \eta   < 2.5$ 2 J > 25 $  \eta   < 2.5$
7	q + t (l v + X) + b	1 l (I), $E_t > 20$ , $  \eta   < 2.5$ 1 bj, $E_t > 25$ , $  \eta   < 2.5$ 1 j, $E_t > 25$ , $2 <   \eta   < 4.5$ $E_t^{\text{miss}} > 20$	$E > 15$ or $M > 15$ $  \eta   < 2.5$ J > 25 $  \eta   < 2.5$ J > 25 $2 <   \eta   < 4.5$

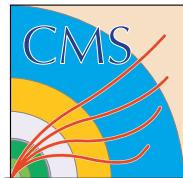
Notations: l(I) - isolated lepton, bj - b-jet, hj - "tau-like-jet", j - light quark jet,

L1 trigger objects: E - isolated e/ $\gamma$  cluster, M - muon, J - jet, T - isolated "tau-like" cluster, collimated in ECAL, values of Et for L1 thresholds correspond to efficiency of about 95%

**Low Et Jets + others  
(by V.Gavrilov)**

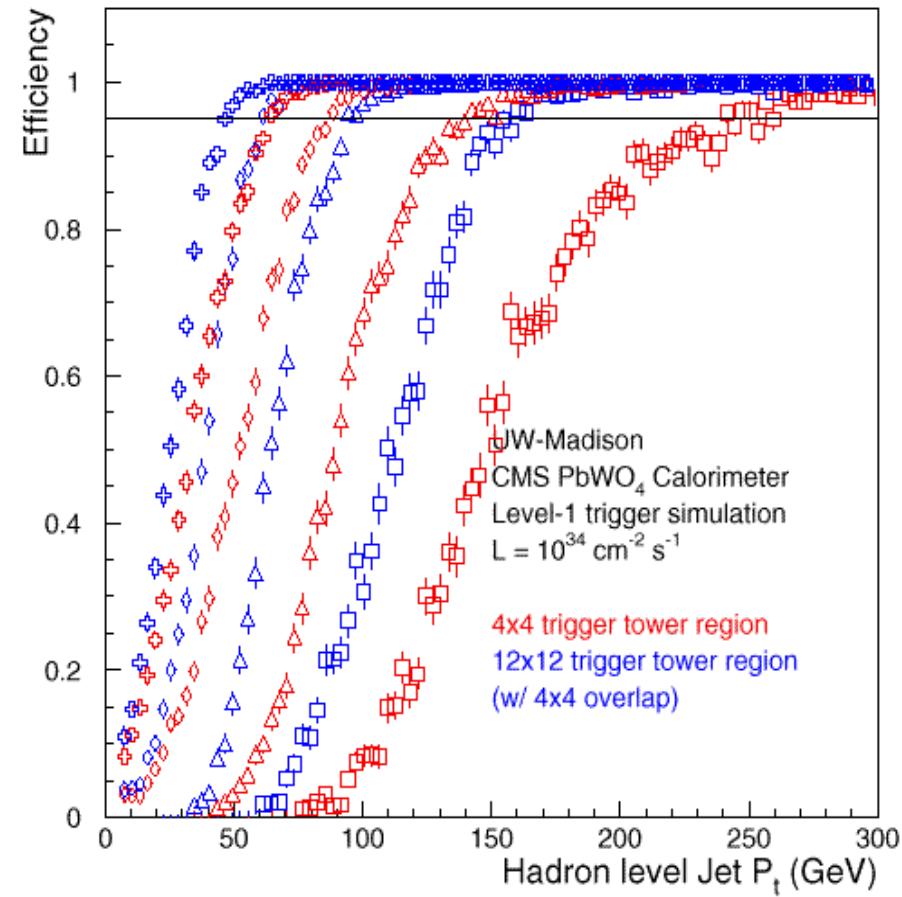
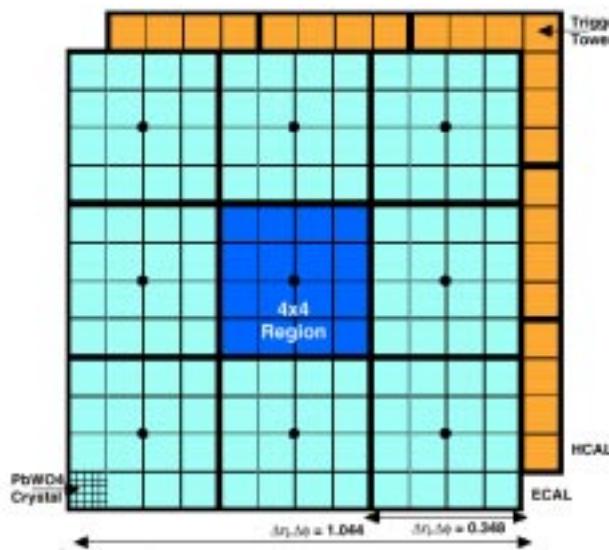
**Et (jet) Threshold  
25 GeV**

**Need rate estimation.**



# L1 Jet Trigger

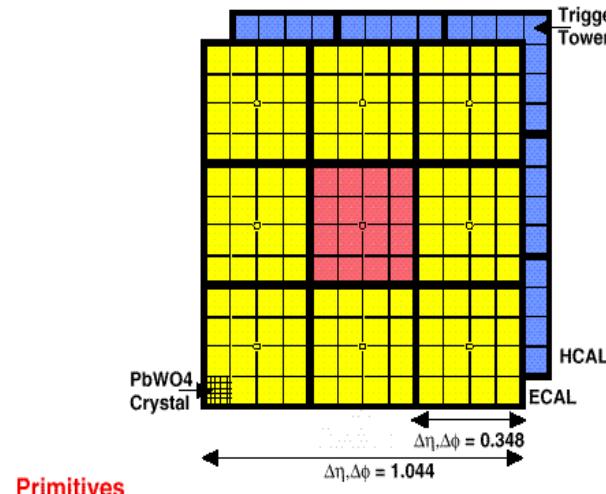
4x4 vs. 12x12



Efficiency turn-on for 12x12 algorithm is sharper than that for 4x4 algorithm.



# New L1 Algorithm



- 4x4  $E_T$  sums of ECAL and HCAL trigger towers
- $\tau$  veto bit set if number of active ECAL and HCAL trigger towers in 4x4 region ( $E_T^{ECAL} > 2$  GeV or  $E_T^{HCAL} > 4$  GeV) is greater than 2

#### Jet Algorithm (sliding window of 4x4)

- Jet  $E_T$  is given by the sum of 12x12 trigger towers overlapping sliding steps of 4x4 with the requirement that central 4x4 is greater than neighbors
- Jet candidates are sorted to find highest energy jets
- Count 4x4 regions above threshold (Handle high jet multiplicity)

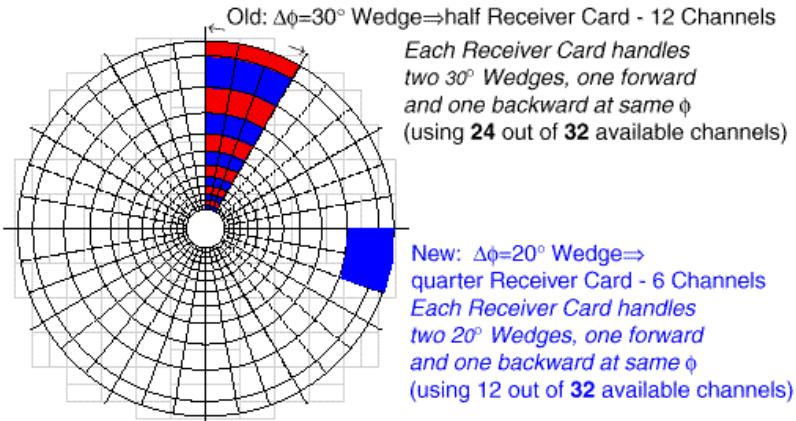
#### $\tau$ Algorithm (sliding window of 4x4)

- $\tau E_T$  is same as Jet  $E_T$
- $\tau$  veto bit should be false in all nine 4x4 regions

#### Missing $E_T$

- 4x4  $E_T$  is converted to  $E_x$  and  $E_y$  using LUT and added over all  $\eta$ .

New: 2 CMS HF Calorimeters mapping onto 12 32-Channel Receiver Cards  
Old: 2 CMS HF Calorimeters mapping onto 6 32-Channel Receiver Cards



Readout segmentation:  $36\phi \times 12\eta \times 2z \times 2F/B$   
New Trigger Tower segmentation:  $18f \times 6h \times 2F/B$   
Old Trigger Tower segmentation:  $12\phi \times 12\eta \times 2F/B$

#### Comment:

No 12x12 at HE-HF boundary  
Need more study!



# Straw Man L1 Trigger Table

Trigger Type	Et Cutoff (GeV)	Rate (kHz)		
		Indiv.	Cumul.	Increm.
Sum Et	400	0.48	0.48	0.48
Miss Et	80	1.29	1.7	1.22
1 e	25	6.84	8.34	6.64
2 e	12	1.45	9.52	1.18
4 jet	100	2.06	10.7	1.16
2 jet	60	2.17	11.6	0.93
3 jet	30	3.16	13.3	1.7
4 jet	20	2.96	14.3	1.01
Jet + e	50 +12	1.35	14.9	0.59

(95% efficiency point for offline jets at roughly at 2x the L1 threshold. For MET, about 2.5x?)

By Trigger group  
for the original  
baseline L1 algorithm.



# CMS Software

## CMSJET

- parameterized (fast) MC (see Salavat Abdullin's talk)

## CMKIN

- Interface to PYTHIA, ISAJET, HERWIG

## CMSIM

- Detector Simulation with GEANT3
  - plus Event Reconstruction in Fortran

## ORCA

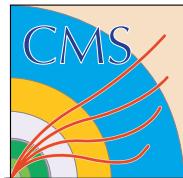
- Event Reconstruction in OO/C++

## OSCAR

- Detector Simulation with GEANT4
  - full (i.e. Slow) and parameterized (i.e. Fast)

## IGUANA

- Interactive Graphical User Analysis



# CMKIN / CMSIM 116

## CMKIN

- output- generated particles in ntuple file
- Need
  - an interface to PYTHIA v6.

## CMSIM

- output- hits (energy in crystals and scintillator plus depth,eta,phi index, time slice) in fz files.
- Need
  - update HE geometry (nose and 1 layer less).
  - add dead material around and behind EE.
  - more realistic cables etc. for Tracker.



# ORCA

ORCA 3 - Oct '99 // ORCA 4 - Feb '00

Unified calorimeter code for ECAL  
and HCAL

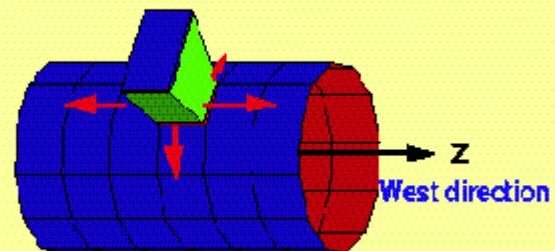
## Some documentation:

- ORCA home page
  - CMSDOC > software > CMS OO Project Page >
- S. Eno's talk at HLT meeting (4-Nov-99)
  - JPG home page > meetings > HLT workshop (Nov4) > Overview...by S. Eno
- "An Object Oriented Jet Finder Library" by H-P Wellisch
  - (CMS Note 1999/034)

JPG Home page =  
<http://hepd01.physics.umd.edu/JPG>

## Geometry/Navigation

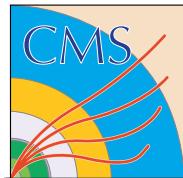
- navigation over hcal cells and towers



no indexes; West, East, North, South, Up, Down

## CaloBase.h

- EcalBarrelBase.h
- EcalEndcapBase.h
- EcalTowerBase.h
- HcalBase.h
- HcalTowerBase.h
- PreshBase.h
- PreshTowerBase.h



# ORCA (2)

## Objects

### HITS (Signal and Min-bias)

### DIGI (i.e. RHIT)

- pile-up: 5 (10) bunch crossing for HCAL (ECAL) +noise
- pulse shape simulation
- pulse shape analyzer --> GeV.
  - simple energy scale

### L1Primitive

- similar to DIGI, but for Trigger towers

### EcalPlusHcalTower

- sum of ECAL and HCAL digi's.

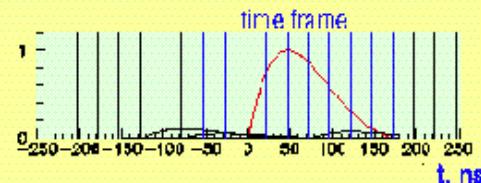
### Jets

- algorithm (iterative cone, K\_T, etc.)

### MET

- (in progress)

- possibility for FAST and REALISTIC digitization



- possibility of changing calibration constants

### Calibrated\_Jets

- on detector effect (not yet)

### Calibrated\_MET (?)

- on detector effect (not yet)

## Analysis with paw/ntuple

- a ntuple maker: JPG Home page > ntuple maker



# OSCAR

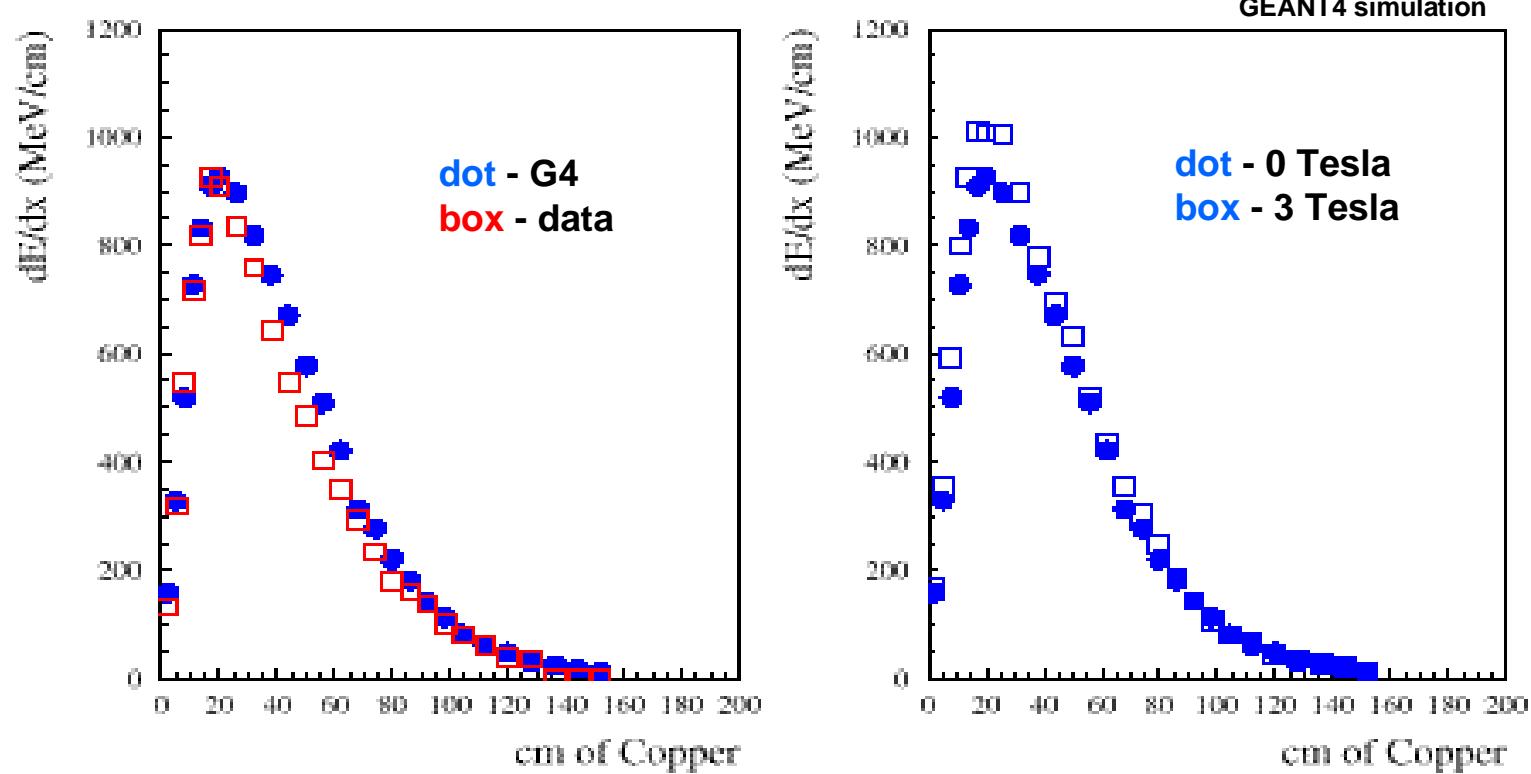
## New Detector Simulation Software using GEANT4

- FULL replaces CMSIM
  - CMS setup:
    - geometry, hits & magnetic field - almost done
    - testing physics processes - in progress
  - Test beam setup:
    - to test hadron shower generator in GEANT4
    - '96 H2 setup: some results on “HCAL only”
    - '99 H2 setup: phi slice of CMS setup (done)
    - (V.Lefebure), Sunanda Banerjee, Sudeshna Banerjee
- FAST replaces CMSJET
  - needed for Physics TDR



# '96 H2 test setup

## Longitudinal Shower Profile for 50GeV pions (V. Lefebure)



HCAL = (1 x 2cm Cu) + (6 x 3cm Cu) + (14 x 6cm Cu) + (6 x 8cm Cu)  
with (2mm plastic + 4mm scintillator + 1mm plastic)



# JPG

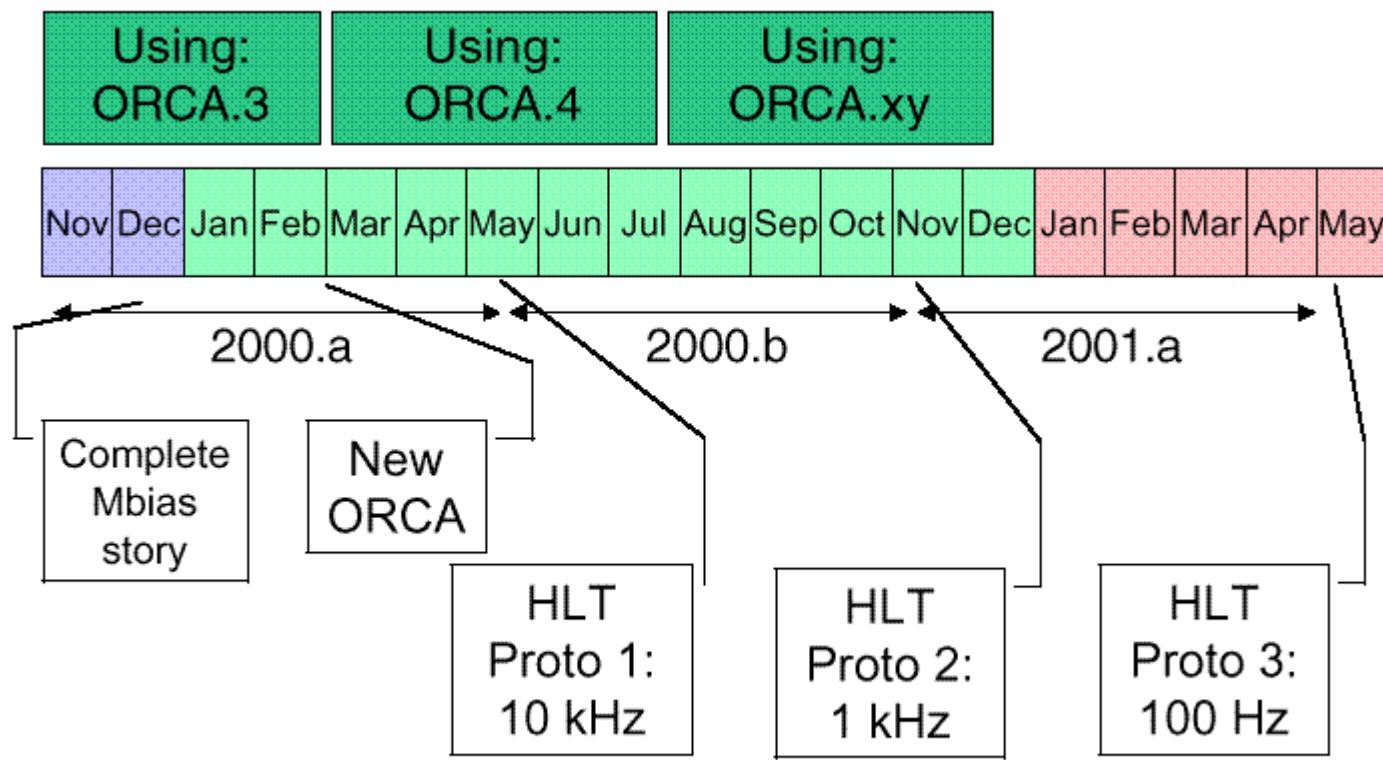
## Jet and MET Physics Group

- Coordinator: Sarah Eno ([eno@physics.umd.edu](mailto:eno@physics.umd.edu))
- Home page: <http://hepd01.physics.umd.edu/JPG>
- **One of four CMS physics groups (P.Sphicas)**
  - other groups: Electron/Photon (C.Seez), Muon (U.Gasparini), b/tau (A.Caner)
- **Priority:**
  - to assist with the May HLT (that's higher-level trigger, for us newbie's) milestone.
    - For the high luminosity trigger table, find how to get a factor of 10 rejection from L2 using only calorimeter data and with good efficiency for  $H \rightarrow \tau\tau$ 
      - Calo/Jet/MET code development in ORCA
      - MC event analysis
- **Meetings:**
  - Video conference every two weeks
  - good minutes on the Web home page.
    - including a link to the HLT workshop in Nov'99



# HLT Time Scale

(Driven by DAQ TDR due in 2001)





# Suggested Plan for Next 6 months (by P.Sphicas)

- Jet/missing ET
  - ORCA additions:
    - Calo calibration (jets mainly)
    - Persistency of objects below
  - Objects/algorithms:
    - Missing  $E_T$ : understand resolution, rates, etc; “bank” equivalent
    - Jets: understand/establish baseline code; “bank” equivalent
  - Goal:
    - Update all Lvl-1 rates (highest priority)
    - Choose two challenging jet channels for physics, establish they are doable; by Lvl-1 Trigger TDR...
    - Lvl-2 rates given HLT objects

\* See his summary talk at HLT meeting (4-Nov-99) on plan for others (“Electron/Photon”, “Muon”, “b/tau”) and wish lists.

JPG Home page > meetings > HLT workshop > “Goals for next 6 months”



# Jet/MET People

(from S. Eno's transparency on Nov'99)

## ORCA code

Frank Behner

David Stickland

Chris Tully

Hans-Peter Wellisch

Sasha Nikitenko

Teresa Monteiro

Shuichi Kunori

## ORCA testing

Sarah Eno

Sasha Nikitenko

## L1 requirements

Sridhara Dasu

Sasha Nikitekno

Ed McCliment

## HLT algorithms

Sasha Nikitenko

Dan Green

Shuichi Kunori

## Jet/Met resolutions

Dan Green

Weimin Wu

Shuichi Kunori

## Data Sample Production

Rick Wilkenson

Vivian O'Dell

Werner Jank

Jelica Draskic-Ostojic

Salvadat Abdoulline

Sasha Nikitenko

## Physics Input

Daniel Denegri

Ritva Kinnunen

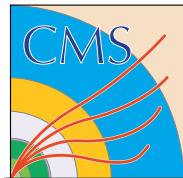
Volker Drollinger

Sasha Nikitenko

Ed McCliment

Dan Green

*Of course, I've forgotten  
people!! Please forgive me!!*



# JPG Task List (as of 8-Jan-00)

> Understand the effect of the true HCAL pulse shape on the trigger rates (Chris Tully & Sarah Eno)

- 1) put proper HCAL pulse shape into digitization routine
- 2 ) figure out how to best choose the bunch crossing for HCAL energy
- 3) figure out the percent of towers whose bunch crossing is misidentified
- 4) figure the effect of this on trigger rates  
figure out how to optimize missing Et resolution in ORCA (Pal Hidas, Salavat Abdoulline)

> improve tau algorithms for low mass higgs (Sasha Nikitenko)

> Design best L1 and L2.0 trigger path, and triggers to monitor the efficiency of these triggers, for

- 1) gg->Hbb->tautau bb (Sasha Nikitenko)
- 2) gg,qq -> qqh -> qq tau tau (S. Nikitekno)
- 3) SUSY
- 4) other???

> Understand if it is possible to do ttH -> ttbbbar offline. If so, design best L1 and L2.0 trigger path for this channel. (Weimin Wu, Shuichi Kunori)

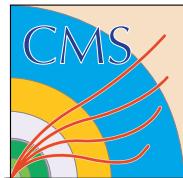
> properly calibrate Hcal, HF (Eugeny Doroshkevic, Silvia Arcelli)

> understand which reasonable parameters for min bias samples give the worst MET resolution.

> work on optimization of use of HF in trigger (Sergei Petrushenko, Ed McCliment)

> work on very-far-forward calorimeter feasibility studies (Kunori)

> work on low Et jet triggers ( Andrei Krokhotin )



# MC Event sample

The following sample has been produced for HLT'99 study  
and available at CERN (and Fermilab).

(See JPG Web Home page > MC samples)

## QCD background

PT range of Bin (GeV)	# GEANT'ed (kevents)
15-20	40
20-30	240
30-50	100
50-80	40
80-120	16
120-170	9.3
170-230	1.2
230-300	1.2
300-380	1.2
380-470	1.2

Binning optimized for current strawman L1 table,  
which emphasizes e/gamma triggers but actually  
seems to work pretty good for us so far, too.

## Signal

### Higgs

#### Milestone process

$gg \rightarrow Hbb \rightarrow evv \text{ jet} v bb$  (200 GeV Higgs)  
 $\rightarrow \text{jet} v \text{ jet} v bb$  (200 GeV Higgs)  
 $\rightarrow \text{jet} v \text{ jet} v bb$  (500 GeV Higgs)

also, have become aware of other challenging  
channels...

$gg, qq \rightarrow qqh \rightarrow qq\tau\tau \rightarrow qq evv \text{ jet} v$  (135 GeV Higgs)  
do we need a VF jet trigger?

$pp \rightarrow tth \rightarrow ttbb \rightarrow bqqbqqbb$  (110 GeV Higgs mass)  
lots of jets, no MET

plus some “easy” SUSY points



# Challenges

## Jet: energy scale (and resolution)

- correction depends on energy and eta

## MET: resolution

- below ~100GeV at 10E34

## Trigger: acceptable rates and flexibility

- L1 output- 75kHz (~1/10th for Jets & MET)
- L2 output- 1kHz / L3 output- 100Hz
  - need good understanding of CUTS used in offline physics analysis to construct a model trigger table.

## Data Analyses:

- 10E9 events, 10E15 bytes per year
- distributed: CERN - centers- universities - desk



# Summary

## Jets/MET

- Moving to
  - higher luminosity ( $10E34$ )
  - lower energy: Jets (below 30GeV), MET (below 100 GeV) at  $10E34$
- Our understanding much improved, but need a lot more work.

## OO Software (ORCA,OSCAR)

- A lot of progress. (usable!)
- Need more test and more users.
- Need stability.

**Need Help! Volunteers?**

**- It's fun! -**